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# Assessing the consequences of policy measures on long-term agricultural productivity – Quantification for Flanders

Lieselot Boone<sup>a, b, \*</sup>, Jo Dewulf<sup>a</sup>, Greet Ruysschaert<sup>b</sup>, Tommy D'Hose<sup>b</sup>, Hilde Muylle<sup>b</sup>, Isabel Roldán-Ruiz<sup>b, c</sup>, Veerle Van linden<sup>b</sup>

<sup>a</sup> Department of Green Chemistry and Technology, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, 9000, Gent, Belgium

<sup>b</sup> Flanders Research Institute for Agricultural, Fisheries and food (ILVO), Burgemeester Van Gansberghelaan 92, 9820, Merelbeke, Belgium

<sup>c</sup> Department of Biotechnology and Bioinformatics, Faculty of Sciences, Ghent University, Technologiepark 927, 9052, Gent, Belgium

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## ABSTRACT

Policy can influence the long-term agricultural resource productivity by stimulating/discouraging farmers to apply certain land use practices (LUP), as LUPs may affect the soil organic carbon (SOC) stock, hence influencing crop productivity. We introduce six policy strategies, each characterized by its own mix of LUPs, for the Flemish agricultural sector. Three strategies reveal the impact of the Common Agricultural Policy (CAP) in the past, while others reflect the potential of the CAP and the application of compost. We use the life cycle impact assessment indicators 'SOC change' and 'biomass productivity loss', which account for the impact of LUPs on SOC and yield, to assess the effects on long-term productivity. To avoid burden shifting, also the resource footprint is calculated. Several farm management systems (FMS) are distinguished, each characterized by a specific combination of farm type, agricultural region, rotation system and manure type. The results highlight that policies such as the CAP significantly contribute to a better SOC stock and (to a lesser extent) productivity. Furthermore, applying extra compost seems to be promising: it can result in an increasing resource productivity and reduced resource footprint. It is important to consider the resource footprint as only for one strategy the resource consumption outweighs the benefit (i.e. reduction in N fertilizer) in the short or medium term, while also being beneficial in terms of resource productivity. As the results differ per FMS, a differentiated approach is advisable when specific LUPs are stimulated in the context of sustainable farming.

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## 1. Introduction

The main challenge facing agriculture is providing food and other bio-based resources for the growing population while simultaneously protecting natural capital (Brady et al., 2015). The European Union's (EU) Common Agricultural Policy (CAP) is a long-existing partnership between agriculture and society and between Europe and its farmers that, amongst others, aims to protect farmers and guarantee them a reasonable standard of living while tackling this challenge (EC, 2018a). Historically, the CAP stimulated high yield production systems in order to ensure food security, thus promoting agricultural intensification (Stolte et al., 2016). While

agricultural intensification lays at the basis of the productivity increases achieved in the last decades, it also resulted in increased energy use, environmental pollution, and water and land degradation (Foley et al., 2011). This led to a redefinition of the objectives of the CAP from the rather narrow aim of providing affordable food to European citizens, to a policy that promotes sustainable farming, which refers to both addressing the public (food) demands while simultaneously safeguarding biodiversity and protecting nature (including soil capital). For instance, the 2013 CAP reform introduced a compulsory set of greening rules. Their main objective is contributing to the environmental and climate goals of the CAP and to ensure long-term sustainable agriculture (EC, 2018a).

Intensive farming has contributed to different forms of land degradation. In Europe, much attention has been given to loss of soil organic carbon (SOC) (Schieffer et al., 2016; Stolte et al., 2016), because SOC affects several soil characteristics and processes and controls important functions such as productivity of agricultural

\* Corresponding author. Department of Green Chemistry and Technology, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, 9000, Gent, Belgium.

E-mail address: [lieselot.boone@ugent.be](mailto:lieselot.boone@ugent.be) (L. Boone).

soils (D'Hose et al., 2014; Wiesmeier et al., 2016). The decline of soil organic matter (SOM) in mineral soils is widespread in Europe, and is a matter of concern (Stolte et al., 2016). While climate is expected to be the main driver for SOM changes in the long term, land management practices might have the largest impact in the short term (Stolte et al., 2016; Wiesmeier et al., 2016). Also within the CAP, the importance of increasing and managing the SOC to enhance soil health and fertility is addressed. For instance, since the Mid Term Review of the CAP in 2003, some countries in the EU defined a minimum level of SOC that farmers need to maintain to receive direct income support (LNE, 2014). Several decisions made by farmers (indicated as 'land use practices' (LUP)) may impact the SOC stock. For instance, cultivation of cover crops (CCs) and crop residue management can affect the SOC stock. The extent of impact of the latter will differ according to, amongst others, the quantity of residues being removed and the crops involved in the rotation system (e.g. cereals with possible incorporation of crop residues into the soil are more appropriate to maintain the SOC stock than monoculture silage maize) (LNE, 2014; Rombouts et al., 2014; Smith et al., 2012; Stolte et al., 2016). Besides, increasing the input of organic materials into the soil can be achieved by organic fertilization. In this case, not only the quantity, but also the quality and the duration of application are relevant parameters (Bai et al., 2018; Oberholzer et al., 2012). Organic fertilizers can be of animal (e.g. pig slurry), vegetal (e.g. green compost) or mixed origin (e.g. digestate). The fertilizers will differ in carbon content, but are also a source of other nutrients (e.g. N, P), which will often determine the maximum quantity that can be applied in order to meet the fertilization standards (Rombouts et al., 2014).

To assess the environmental sustainability of LUPs, Life Cycle Assessment (LCA) has been identified as a powerful tool. It addresses the potential environmental impact (in terms of environmental consequences or resource consumption) of a product/service throughout its life cycle (ISO, 2006). Guidance about the most relevant environmental impact categories for several products per sector in order to facilitate comparing LCA results of the same products is given in the Product Environmental Footprint studies (EC, 2018b). The extent of an impact can be assessed at an early stage in the cause-effect chain (midpoint level) or as the final effect on areas of protection (AoPs) at endpoint level (Vidal Legaz et al., 2017). Traditionally in LCA, three AoPs or 'safeguard subjects' are considered: human health, natural resources and ecosystem quality (Sonderregger et al., 2017).

Correspondingly, LCA can be useful to evaluate and compare possible sustainable land management options. When doing so, it is important to account for the impact of LUPs on soil quality (Vidal Legaz et al., 2017). From an agricultural point of view, the main focus of good soil quality is to protect its provisioning role, corresponding to the AoP natural resources (Boone et al., 2018a; Dewulf et al., 2015). A few methods exist to assess long-term effects of agricultural LUPs on (the loss of) resource productivity under the AoP natural resources (Boone et al., 2018a; Brandão & Milà I Canals, 2013; Morais et al., 2016; Teixeira et al., 2018). In contrast to the other methods, Boone et al. (2018a) also map the relationship between SOC stock and biomass productivity. The indicator 'SOC Change' (SOC<sup>2</sup>) designates the extent to which the SOC stock changes in a long-term perspective when non-sustainable, instead of sustainable LUPs, are applied. These SOC changes may affect the yield, defined by the indicator 'Biomass Productivity Loss' (BPL).

In addition to efficient exploitation of the available land by striving for good soil quality, sustainable land management implies the reduction of environmentally harmful agricultural inputs (e.g. agrochemicals) (Alvarenga et al., 2013a; Schiefer et al., 2016). The life cycle impact assessment (LCIA) method CEENE (Cumulative Exergy Extraction from the Natural Environment) allows

constructing the resource footprint (Alvarenga et al., 2013b; Dewulf et al., 2007). Herein, all resources are expressed in terms of exergy, which is based on the second law of thermodynamics and accounts for both the amount and quality of energy and material (Dewulf et al., 2007).

LCA can therefore help to evaluate the environmental sustainability of agricultural policy measures and to design sustainable policy alternatives. Policy is namely one of the main drivers to orient farmer's choices by stimulating or even prescribing certain LUPs (Stolte et al., 2016). A prominent example are the greening measures in the CAP reform, which affect farmers' choices by stimulating crop diversification and CC cultivation, amongst others. In Flanders (northern region of Belgium), the effect of the greening rules on CC cultivation is also reinforced by other policies. For instance, the Manure Action Plan (i.e. region specific action program of the European Nitrates directive, MAP5), which entered into force in 2015, stipulated focus areas (based on nitrates measurements) for which more strict regulations are valid to avoid exceedance of the nitrate concentration standards. One of those measures is the obligation to sow CCs after the main crop when possible (VLM, 2015). Boone et al. (2018a) identified and quantified positive effects of CCs on long-term productivity. However, the general perception is that these greening measures are mainly contributing to maintaining/increasing biodiversity (AoP ecosystem quality) (EC, 2011), while they have not yet been related to long-term productivity gains. Next, policy is able to guide farmers towards alternative non-synthetic fertilizers such as compost. Although farmers recognize that compost is an excellent soil improver, positively affecting soil quality and soil fertility at the longer term, they are hesitant to use compost in Flanders, due to, inter alia, concerns regarding the varying quality and risks for weeds and contaminants, and the surplus of slurry making it a much cheaper alternative (Viaene et al., 2016).

The objective of this study is to investigate the impact of existing and potential policy measures on the long-term resource productivity and resource footprint (AoP natural resources). We compare policy strategies that are expected to shift the mix of LUPs that farmers apply. While focusing on SOC and productivity, we will discuss (1) what has been realized thanks to the introduction of the greening rules in the CAP reform and other policies stimulating CC cultivation (looking at the past) and (2) the impact of future perspectives regarding improved LUPs with e.g. more CCs or the use of compost as fertilizer. We focus hereby on Flanders. To do so, we first describe the Flemish agricultural sector by discussing farm types (FT) and farm management systems (FMS) that we expect to be responsive to policy measures. Next, we introduce six policy strategies which all encourage/discourage certain LUPs, followed by the data collection needed to compare those strategies in terms of resource productivity and resource consumption. Finally, the results are discussed showing the (potential) impact of policy on long-term resource productivity and resource footprint.

## 2. Material and methods

### 2.1. Arable farming in Flanders

#### 2.1.1. Farm types

The Flemish utilized agricultural area, broadly consisting of (1) arable land, (2) permanent grassland and meadow, (3) perennial crops, and (4) cultivation in greenhouses, amounted 610,971 ha in 2017. In this study, we focus on arable land (423,023 ha), which comprises mostly cereals (30%), fodder crops (42%), and potatoes (12%) (FOD, 2018).

Some farms combine different activities (e.g. mixed arable crop and livestock farming), while others specialize in one particular

type of farming (e.g. field vegetables). [Bernaerts et al. \(2014\)](#) defined a main FT for each Flemish municipality. This subdivision is based on the methodology of [Danckaert et al. \(2009\)](#), which takes two characteristics into account: the number of holdings per FT and the standard output. Similar agricultural profiles are clustered into one FT. They are named after the main activity (or product); in case of more than one prevailing activity, the activities are listed in order of importance. [Table 1](#) summarizes the FTs considered in this study with their respective contribution to Flemish arable land.

Based on [Tits et al. \(2016\)](#) and [Geopunt \(2018\)](#), for each municipality the most prevailing agricultural region (AR) was defined. When linking the ARs with the FTs ([Fig. 1](#)), it is clear that some FTs occur predominantly in one AR (e.g. FT5), while other FTs are more randomly distributed (e.g. FT6).

### 2.1.2. Farm management systems

By combining all FTs and ARs, there are 36 potential combinations, but only 23 combinations occur in Flanders ([Appendix A, Fig. A1](#)). Each FT-AR combination can be characterized by one typical manure type, and a representative rotation system (RS) can be determined. Each specific combination of these four characteristics is hereafter indicated as 'farm management system' (FMS). To define the FMS, the following choices are made:

#### 1. Farm type and agricultural region

We include all 6 FTs listed in [Table 1](#) and select the most frequently occurring ARs per FT. To obtain a representative share, we assured that at least 70% of the arable land per FT is covered ([Fig. A1](#)). In total, ten FT-AR combinations are selected, corresponding to 71% of the Flemish arable land ([Table 2](#)).

#### 2. Manure type

The type of manure (pig slurry or farmyard manure (FYM), which are the two most common types in Flanders ([Vos, 2018](#))), assigned to each FT-AR corresponds to the most prominent available type in all Flemish municipalities belonging to this combination (reference year: 2016) ([Vos, 2018](#)).

#### 3. Municipality

We first select representative municipalities in order to determine a characteristic RS for each FT-AR combination, as large variation exists among regions and among farmers. The selection of representative municipalities is based on agricultural data from the national database (reference year 2016) ([FOD, 2018](#)). The selected municipalities per combination are characterized by (almost) the largest area of both utilized agricultural area and arable land in this FT-AR (e.g. large area of vegetables in FT3).

#### 4. Rotation system

By investigating the agricultural plots of the years 2011–2017, a representative RS for each municipality, which corresponds to a specific FT-AR combination, is determined ([Geopunt, 2018](#)). The representativeness was validated by experts (Department of Agriculture and Fisheries, personal communication, 2018). However, one must keep in mind that the selected RS represent only one of the possibilities. The selection of these RS is motivated in [Appendix A \(Table A1\)](#).

[Table 2](#) displays an overview of the ten FMS considered.

### 2.2. Agricultural policy strategies

The choice of farmers to apply certain LUPs, which affect resource productivity, is often policy driven. In this study, we compare six scenarios, called policy strategies, that all encourage/discourage certain LUPs. First, we focus on the past and estimate what has been realized by growing more CCs, stimulated by policy measures such as the greening measures of the CAP. Second, we look to the future by investigating the maximum potential of policy measures regarding CC and opportunities of fertilization by compost.

#### 2.2.1. Policy strategies reflecting the situation in the past

The policies stimulating CC cultivation (e.g. greening rules of the CAP, MAP5) came into force in Flanders in 2015. We distinguish three strategies, all of them have a distinct distribution of areas that are covered with a RS including no, 1, 2, or 3 CCs, while organic fertilization is equal in all cases. The maximum number of CCs is different per RS as it depends on the crops included in the rotation. The three strategies are:

- **policy\_noCC**: no CC is cultivated;
- **policy2014**: situation in 2014, before implementation of the new policies stimulating CC cultivation;
- **policy2016**: situation in 2016, reflecting the impact of the policy measures implemented in 2015.

We rely on data of Flanders Department of Agriculture and Fisheries to define the number of CCs which were cultivated in each representative municipality in 2014 and 2016 ([Baeten, 2018](#)). The situation regarding CC cultivation in 2016 is similar to that of 2017 ([Baeten, 2018](#)), indicating that policy2016 is still reflecting the current situation. More information can be found in [Appendix A, Tables A2–A11](#).

#### 2.2.2. Policy strategies reflecting future perspectives

Three possible future strategies are introduced:

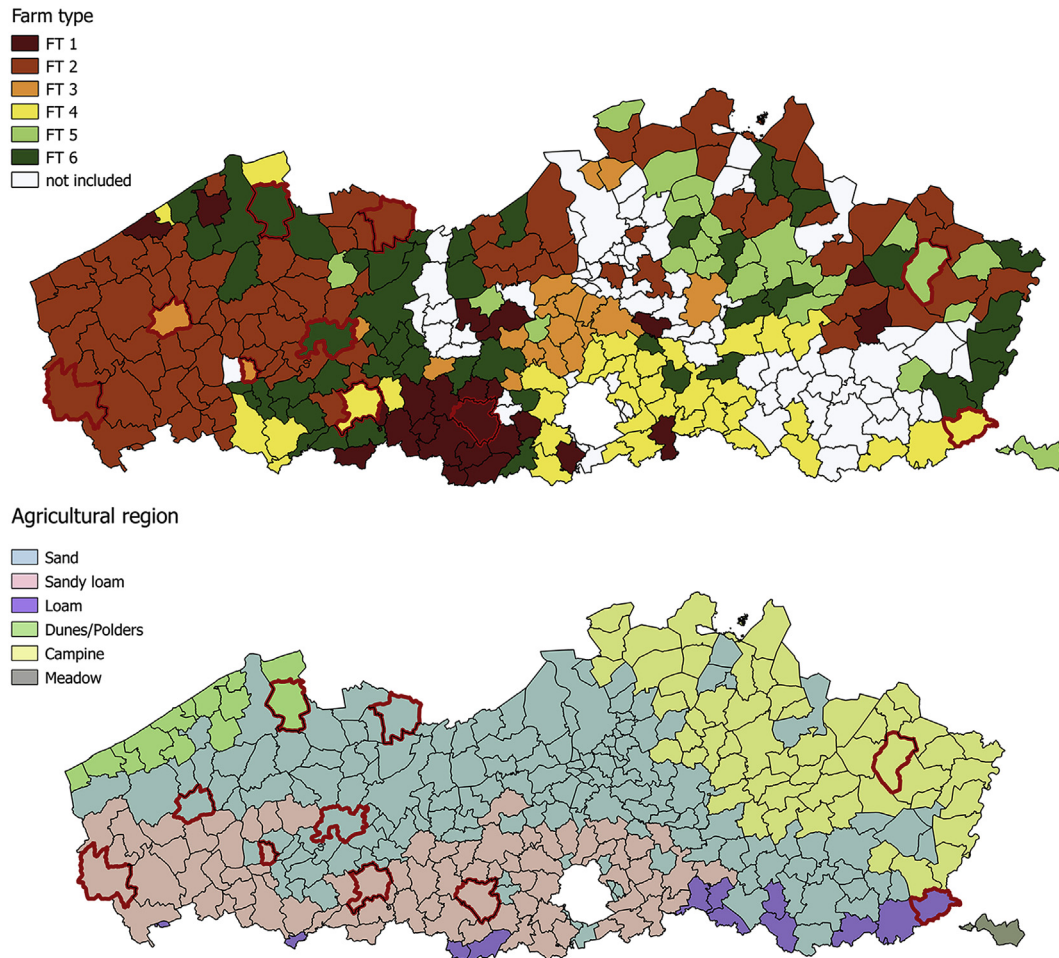
- **policy20xx**: at all fields, RS with a maximum number of CCs are cultivated, while applying standard fertilization quantities ([Appendix B](#));

**Table 1**

Farm types and corresponding agricultural area in Flanders, based on [Bernaerts et al. \(2014\)](#) and [FOD \(2018\)](#).

	Farm type (FT)	% of total arable land
FT1	Cattle <sup>a</sup> farming	6.6
FT2	Intensive livestock farming (poultry, pigs)	43.4
FT3	Field vegetables	3.4
FT4	Mixed arable farming and intensive livestock farming (poultry, pigs)	13.1
FT5	Mixed dairy and intensive livestock farming (poultry, pigs)	7.1
FT6	Mixed intensive livestock (poultry, pigs) and cattle <sup>a</sup> farming	15.9
/	Not in study (fruit, glasshouses, ...)	10.5

<sup>a</sup> Dairy and beef.



**Fig. 1.** Distribution of farm types (FTs) (A) and agricultural regions (B) in Flanders, based on [Bernaerts et al. \(2014\)](#) and [Geopunt \(2018\)](#). Ten representative municipalities are selected (red line). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

**Table 2**

Farm management systems with corresponding characteristics, occurrence in Flanders and representative municipality.

Farm management system (FMS)	Farm type (FT)	Agricultural region (AR)	Typical manure type (pig slurry/ farmyard manure (FYM)) of specific FT-AR	Typical rotation system (RS) of specific FT-AR	Maximum number of cover crops (CC) <sup>a</sup>	Occurrence of FT-AR (% of total Flemish arable land)	Representative municipality
FMS1	FT1	Sandy loam	FYM	Winter wheat – silage maize – silage maize (RS1)	2	5	Ninove
FMS2	FT2	Sand	Slurry	Winter wheat – silage maize – potato – silage maize (RS2)	3	18	Assenede
FMS3	FT2	Sandy loam	Slurry	Winter wheat – potato – silage maize (RS3)	2	16	Poperinge
FMS4	FT3	Sand	Slurry	Cauliflower – potato – leek – bean (RS4)	2	2	Kortemark
FMS5	FT3	Sandy loam	Slurry	Cauliflower – potato – leek – bean (RS4)	2	1	Ingelmunster
FMS6	FT4	Sandy loam	FYM <sup>b</sup>	Winter wheat – potato – sugar beet – winter wheat – silage maize (RS5)	3	6	Oudenaarde
FMS7	FT4	Loam	Slurry	Winter wheat – potato – sugar beet – winter wheat – silage maize (RS5)	3	5	Riemst
FMS8	FT5	Campines	Slurry	Silage maize (RS6)	1	6	Peer
FMS9	FT6	Sand	Slurry	Silage maize – silage maize – potato – grain maize (RS7)	3	9	Deinze
FMS10	FT6	Polders	FYM	Winter wheat – silage maize (RS8)	1	3	Damme

<sup>a</sup> Actual number of CCs cultivated is policy driven.

<sup>b</sup> Although pig slurry is expected for this FT, FYM is most prominent ([Vos, 2018](#)).



- **policy20yy**: at all fields, RS with a maximum number of CCs are cultivated and a surplus of 15 t ha<sup>-1</sup> green compost is applied above standard fertilization;
- **policy20zz**: CC cultivation happens according to the situation in 2016, while 60% of the standard quantity of manure is supplemented with green compost up to the fertilization standards for nitrogen (N) and phosphorus (P) (VLM, 2018).

Policy20xx indicates what still can be realized when the policy rules would be fully exploited in terms of CC. Policy20yy goes beyond that by also incorporating compost, above the standard fertilization dose (Appendix B). Consequently, this strategy is restricted by current legislation. In contrast, policy20zz reflects the actual situation (2016) regarding CC cultivation and complies with the current legislation. However, it still is a perspective as it implies an increase in the use of compost (section 1).

### 2.2.3. Farmers respond to policy strategies with a certain land use practice

Each of the strategies considered is characterized by a specific mix of LUPs. We distinguish several LUPs in relation to use of CCs and fertilization.

- o **LUP<sub>CC0</sub>, LUP<sub>CC1</sub>, LUP<sub>CC2</sub>,...**: respectively, 0, 1, 2, ...CCs are cultivated per RS; manure (slurry/FYM) application up to fertilization standards;
- o **LUP<sub>COM15</sub>**: maximum number of CCs in RS are cultivated; 15 t ha<sup>-1</sup> green compost applied above normal fertilization dose;
- o **LUP<sub>COM/MAN,CC0</sub>, LUP<sub>COM/MAN,CC1</sub>, LUP<sub>COM/MAN,CC2</sub>,...**: respectively, 0, 1, 2, ...CCs are cultivated per RS; 60% of the normal quantity of manure is supplemented with green compost up to the fertilization standards.

For each FMS, the distribution of LUPs applied on the total arable land related to a certain policy strategy is different. In Table 3, an example is given for FMS10. The data of the other FMS as well as information about fertilization doses related to each LUP, are summarized in Appendix B.

## 2.3. Data collection

### 2.3.1. Development of characterization factors

The LCIA indicators SOC<sup>2</sup> and BPL are used to account for the long-term impact of agricultural LUPs on resource productivity under the AoP natural resources (Boone et al., 2018a). While the first designates long-term SOC changes due to particular LUPs, BPL enables the assessment of how the change in SOC stock affects biomass productivity.

In function of policy strategies, a range of LUPs and RS are analyzed. Therefore, we needed to develop additional characterization factors (CF; value indicating the impact of LUP applied to a

certain FT-AR on SOC and biomass productivity) to those available in Boone et al. (2018a).

2.3.1.1. *Calculation procedure.* For a discussion on the methodology used, see Boone et al. (2018a) and Appendix C. In brief:

### 1. Calculation criteria

- Reference period is 30 years.
- Optimal SOC stock (SOC<sub>opt</sub>) equals the average of the optimal SOC range in terms of productivity determined per AR (Table C1).
- Initial SOC stock (SOC<sub>init</sub>) is defined per AR SOC<sub>init,p50</sub> (Table C1).
- CFs are unique to and valid for a particular RS.

### 2. Sustainable LUPs (LUP<sub>sus</sub>)

LUP<sub>sus</sub> imply two aspects:

- The SOC management needed to maintain (or approach) SOC<sub>opt</sub> for 30 years (Fig. C1). LUP<sub>sus</sub> result also in an optimal yield (Y<sub>opt</sub>). In this study, the SOC management includes CC cultivation and, if needed, additional FYM application (above standard fertilization). The SOC management is determined by modeling and depends on soil texture, SOC<sub>opt</sub>, and RS (Table C2). All CCs are represented by white mustard.
- The minimal consumption of mineral N fertilizers to still obtain Y<sub>opt</sub>, which is determined by modeling (Table C2).

### 3. Reference state

SOC<sub>opt</sub> is used to define the LUP<sub>sus</sub>. However, SOC<sub>init,p50</sub> is lower than SOC<sub>opt</sub>. Thus, applying LUP<sub>sus</sub> at SOC<sub>init,p50</sub> results in an increase of SOC stock and yield over a period of years towards the optimal values. SOC stock and yield obtained when applying LUP<sub>sus</sub>, SOC<sub>sus</sub> and Y<sub>sus</sub>, respectively, correspond to the reference state.

## 4. Application of LUPs as consequence of potential policy measures

Policy measures may induce other LUPs than LUP<sub>sus</sub> (section 2.2). While LUP<sub>sus</sub> are characterized by SOC management that safeguards the long-term productivity, non-sustainable LUPs result in a lower SOC stock, while other (advanced) LUPs may lead to a higher SOC stock (Fig. C1).

2.3.1.2. *Applied models.* Analogous to the study of Boone et al. (2018a), the globally-applied RothC 26.3 model, run in 'R' (SoilR package), is used to model the impact of LUPs on SOC stocks over time (Coleman and Jenkinson, 2014; Sierra et al., 2012). To simulate the yield response (dry matter (DM) production) to changes in SOC level, the EU-Rotate\_N model (version 1.8) is used (Rahn et al., 2009, 2010). The model is also used to define the minimum amount of N fertilizer needed to obtain Y<sub>opt</sub>. The model input and

**Table 3**

Application degree (%) of land use practices (LUP) per policy strategy (elaborated for FMS10). For policy2014, policy2016, and policy20zz (using 2016 as reference year), the distribution is based on data of the Flemish government (Baeten, 2018). Policy\_noCC is a hypothetical situation, policy20xx and policy20yy reflect an assumption of the future response of farmers to policy measures.

	Application degree of LUP (%)					
	PAST			FUTURE		
	policy_noCC	policy2014	policy2016	policy20xx	policy20yy	policy20zz
LUP <sub>CC0</sub>	100	55	28	0	0	0
LUP <sub>CC1</sub>	0	45	72	100	0	0
LUP <sub>COM15</sub>	0	0	0	0	100	0
LUP <sub>MAN/COM,CC0</sub>	0	0	0	0	0	28
LUP <sub>MAN/COM,CC1</sub>	0	0	0	0	0	72

fertilization data are summarized in [Tables B3, C2 and C3](#).

### 2.3.2. Life cycle based resource accounting

Applying another LUP might imply other/extra inputs (e.g. fuel, seed for CC). To avoid burden shifting, we determine the resource footprint of each LUP. To do so, the thermodynamic LCIA method CEENE is applied. This method evaluates the cumulative resource consumption in terms of exergy and covers eight resource categories: fossil fuels, nuclear energy, metal ores, minerals, nuclear energy, water, abiotic renewable and land resources ([Alvarenga et al., 2013b](#); [Dewulf et al., 2007](#)). In this way, we account for all natural resources necessary to cover the inputs related to the LUPs, such as fuel to apply extra compost, seed for CCs, etc.

In this study, the LUPs differ in terms of fertilization or CC cultivation, and consequently, are all associated with a different resource consumption ([Table D1](#)). Furthermore, the LUPs affect the advised quantity of synthetic N fertilization, which is computed by making use of the Demeter-tool ([LNE, 2014](#)) as explained in [Appendix D \(Table D2\)](#).

The exergetic value of the crops is calculated in [Boone et al. \(2018b\)](#), except for vegetables. In a similar way to the method in [Boone et al. \(2018b\)](#), their exergy content is determined ([Table D1](#)).

## 3. Results and discussion

The calculated CFs for the indicators  $SOC^2$  and BPL for the LUPs applied under the policy strategies are summarized in [Tables E1–E2](#). The CFs indicate the cumulative carbon deficit and cumulative yield loss per year, respectively, when considering a period of 30 years and calculating the average. These CFs are used to compare policy strategies in terms of resource productivity and resource consumption. In this study, only the impact of the foreground system is considered, while indirect land use fluxes (e.g. due to changes in seed production) are out of scope.

### 3.1. Impact of policy on SOC stock and biomass productivity

In [Fig. 2](#), the long-term effect on SOC stock and productivity by implementing other policy strategies than policy2014 is given per FMS. To do so, first, the yearly average SOC or yield credit/deficit that would exist when a certain policy strategy (and thus mix of LUPs) is applied over 30 years (section 2.3.1) is calculated and then, the outcome is compared to those of policy2014 (before implementation of policies stimulating CCs, e.g. greening measures).

#### 3.1.1. Looking at the past

[Fig. 2A](#) demonstrates what has been already achieved in terms of SOC. For all FMS, policy\_noCC is performing worse than policy2014, indicating the positive effect of CC cultivation on SOC stocks. However, there is a big variation among FMS. For instance regarding FMS4 and FMS6, the SOC stocks are, respectively, 2.41 and 0.18 t C ha<sup>-1</sup> yr<sup>-1</sup> lower than the fields under policy2014. This can be explained by a different area still covered by RS without CCs in 2014, 33 and 88%, respectively ([Tables A5–A7](#)).

Striking is the impact of policy2016 for all FMS, proven by the significantly higher SOC stocks than under policy2014. The differences range from 0.16 (FMS7) up to 1.67 t C ha<sup>-1</sup> yr<sup>-1</sup> (FMS8). The large variability between FMS can be explained by differences in increase in CC cultivation between 2014 and 2016 ([Tables A2–A11](#)), and by specific characteristics of the FMS. Indeed, other RS (with different maximum number of CCs), other carbon addition due to other crops in RS and other manure type applied, and other ARs, all affect the SOC dynamics.

Calculating the weighted average among all FMS, the SOC stocks are 1.33 lower and 0.83 t C ha<sup>-1</sup> yr<sup>-1</sup> higher compared to

policy2014 when policy\_noCC and policy2016, respectively, are implemented.

The impact on yield is represented in [Fig. 2B/D](#). Each crop responds differently upon changes in SOC content and fertilization ([Boone et al., 2018a](#)). To account for the uncertainty regarding the  $SOC_{init}$ , error bars indicating the first and third quartile, corresponding with yield losses at  $SOC_{init,p25}$  and  $SOC_{init,p75}$ , respectively, are indicated.

According to our results, some RS do not respond to changes in SOC stock (RS applied in FMS8 and FMS10). This can be due to limitations of the EU-Rotate\_N model which focuses on the relationship between C and N to determine the yield. In this way, other potential positive effects of SOC changes on yield (e.g. effects on soil temperature, on soil structure and thus on rooting) are neglected ([Boone et al., 2018b](#)). Next, other beneficial effects of CC cultivation, such as the impact on biodiversity and erosion prevention, which can therefore impact yield, are also not accounted for. Model uncertainty is however out of scope.

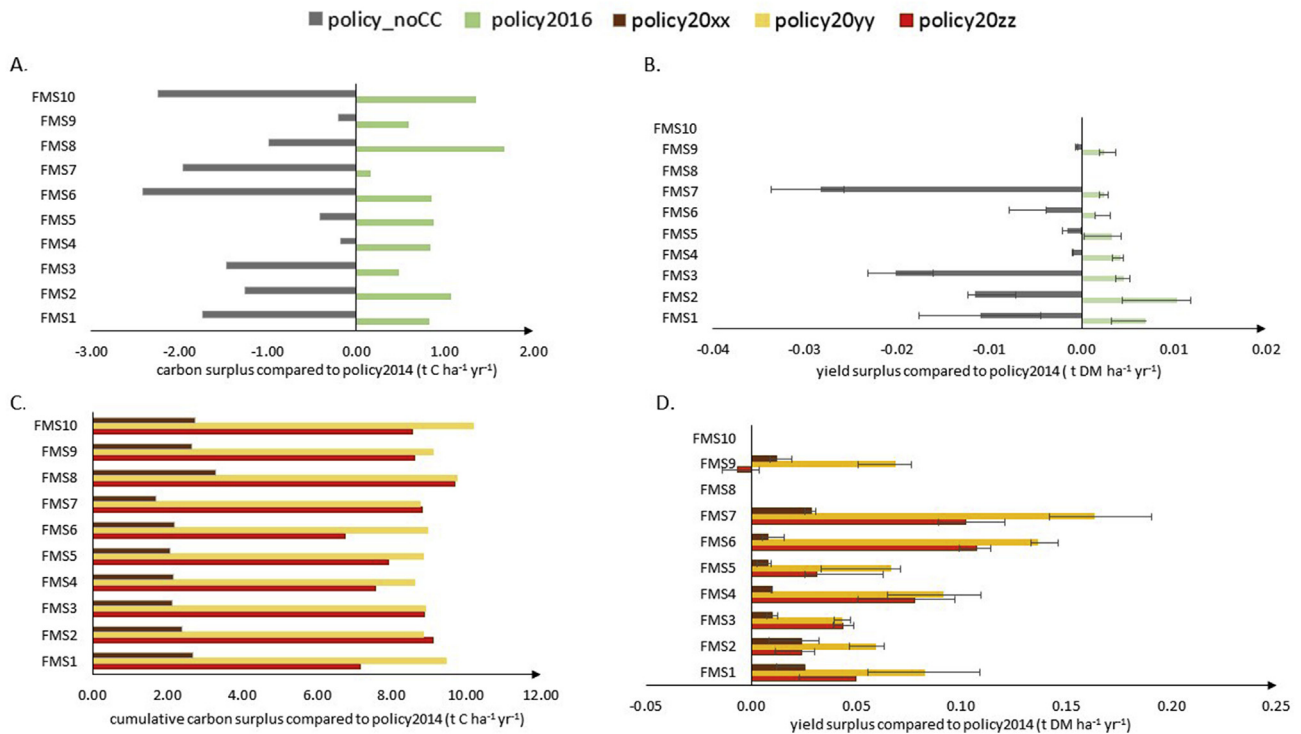
### 3.1.2. Future perspectives

For all FMS, the improvement potential in terms of SOC when the maximum number of CCs would be cultivated, is in the same order of magnitude (policy20xx) ([Fig. 2C](#)). The results are more pronounced for the strategies involving compost (policy20yy and policy20zz) because fertilization happens every year, while CCs cannot be cultivated each year. Furthermore, in policy20yy, extra compost is applied on top of maximum CC cultivation. Also, the effective organic carbon added by compost is higher than by CCs ([Table C3](#)). On average in Flanders, an increase of 2.39, 9.07 and 8.59 t C ha<sup>-1</sup> yr<sup>-1</sup> is realized by implementation of policy20xx, policy20yy and policy20zz, respectively.

The largest differences in SOC stocks between policy20yy and policy20zz are noticed for FMS1, FMS6 and FMS10, the FMS using FYM as organic fertilizer ([Table 2](#)). Since FYM has a higher C content than slurry, replacing part of the FYM by compost influences less the SOC dynamics than it is the case for slurry. While policy20yy reflects the perspective in terms of CC cultivation, for policy20zz, there is even room for improvement by maximum implementation of CCs compared to the situation of 2016. Therefore, this strategy seems to be very promising in terms of SOC.

Regarding yield, the results are more scattered ([Fig. 2D](#)). Extra CCs (policy20xx) and extra compost (policy20yy) result always in higher yields. In contrast, policy20zz seems the best strategy for FMS3, while it causes yield losses for FMS9. The yield changes are effects of different amounts of N available for the crop: each LUP is associated with a certain SOC stock (which will mineralize) and particular quantity of effective N supplied by fertilization ([Table B3](#)). However, one should be careful when comparing and interpreting the results of policy strategies when taking into account the uncertainty range. Furthermore, the EU-Rotate\_N model does not account for other beneficial effects on yield due to better soil quality e.g. better soil structure. This is difficult to model as field studies show that compost affects several soil quality parameters in a positive way (SOC, pH, nutrients), but this does not always result in better crop yields ([D'Hose et al., 2016](#); [Hijbeek et al., 2017](#)).

In Flanders, implementation of policy20xx, policy20yy and policy20zz (applied for 30 years) would result in an increase of 4,434; 19,999; and 11,449 t DM yr<sup>-1</sup>, respectively. So also for yield, the results are in general better for policy20yy and policy20zz than for policy20xx. However, keeping in mind that the SOC/yield improvement is not the main focus of policy when stimulating CC cultivation, the reflected added value of CCs on long-term resource productivity is a remarkable bonus.



**Fig. 2.** Carbon ( $\text{t C ha}^{-1} \text{ yr}^{-1}$ ) and yield ( $\text{t DM/ha/yr}$ ) surplus(+) / losses(−) due to the implementation of other policy strategies than policy2014. First, cumulative carbon and yield surplus are calculated over 30 years for each policy strategy, then the yearly average is calculated and compared to policy2014. A–B: looking at the past; C–D: future perspectives. Results are presented per farm management strategy (FMS). The error bars represent the interval for the results under the condition of  $\text{SOC}_{\text{init},p25}$  and  $\text{SOC}_{\text{init},p75}$ .

### 3.2. Impact of policy on the resource footprint

Policy strategies characterized by LUPs including CC cultivation or use of compost are beneficial in terms of SOC stock and can positively affect the yield (section 3.1). However, those LUPs also entail a certain resource consumption (e.g. fuel, seed) (Table D1). To compare these aspects, we calculate the exergetic benefit/loss of each policy strategy by making the balance between resource consumption and potential benefit (Table D3). The latter is represented by the increased or reduced need for synthetic fertilizers when applying other LUPs than  $\text{LUP}_{\text{CCO}}$  (Table D2). Consequently, for all LUPs, the same amount of N available for the crops is assured, and thus no yield changes are assumed. A period of 30 years is considered and the yearly average is calculated. The final results are presented taking policy2014 as baseline (Fig. 3). For example regarding FMS1, on average,  $0.28 \text{ GJ}_{\text{ex}} \text{ ha}^{-1} \text{ yr}^{-1}$  of synthetic fertilizer can be saved when policy2016 is implemented instead of policy2014, while an extra resource input of  $0.37 \text{ GJ}_{\text{ex}} \text{ ha}^{-1} \text{ yr}^{-1}$  is required. This results in an exergy loss of  $0.09 \text{ GJ}_{\text{ex}} \text{ ha}^{-1} \text{ yr}^{-1}$ . In contrast, for policy\_noCC, the exergy benefits amounts  $0.18 \text{ GJ}_{\text{ex}} \text{ ha}^{-1} \text{ yr}^{-1}$ , because, although the N fertilizer consumption is  $0.51 \text{ GJ}_{\text{ex}} \text{ ha}^{-1} \text{ yr}^{-1}$  higher,  $0.69 \text{ GJ}_{\text{ex}} \text{ ha}^{-1} \text{ yr}^{-1}$  less resources are required compared to policy2014. The high exergetic cost of CCs explains why policy\_noCC results for all FMS in an exergy benefit compared to policy2014.

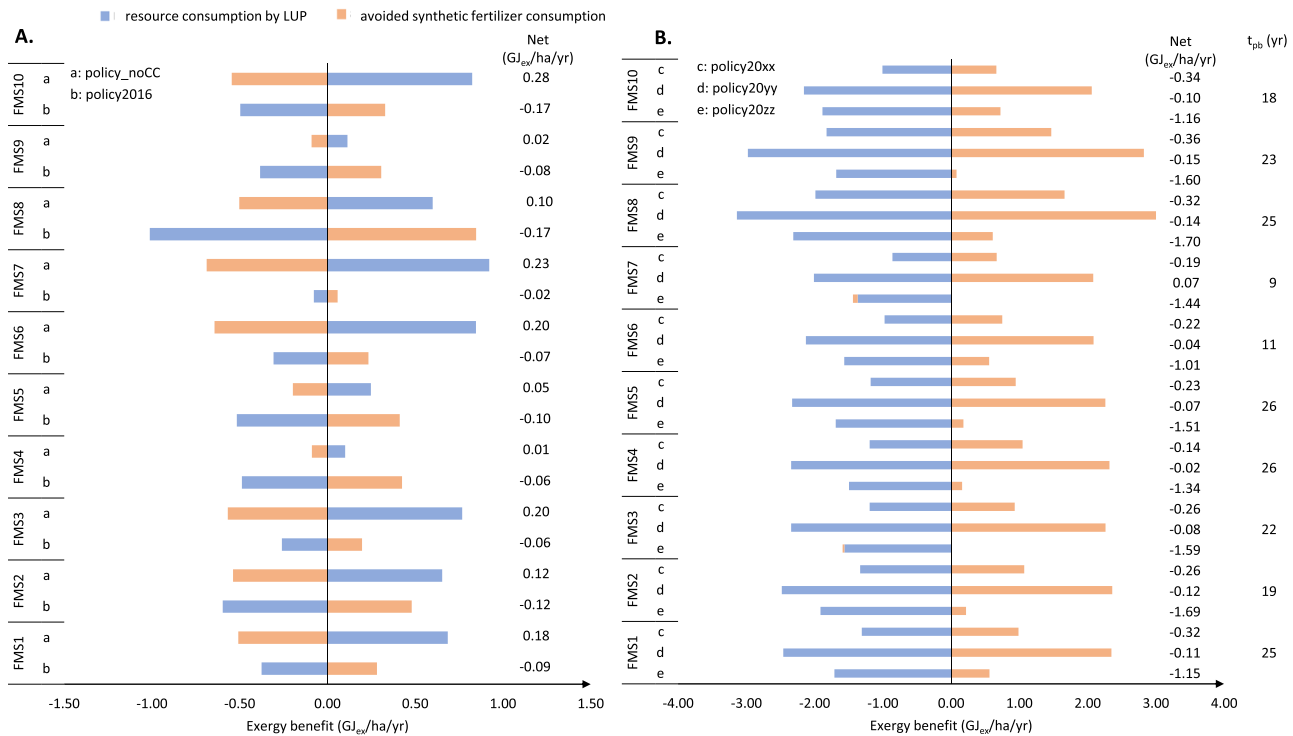
For the strategies reflecting the future, the benefits generally do not outweigh the costs, due to the high number of CCs cultivated. The weighted average over Flanders shows an exergy benefit of  $0.14 \text{ GJ}_{\text{ex}} \text{ ha}^{-1} \text{ yr}^{-1}$  for policy\_noCC compared to policy2014, the other strategies result in an exergy loss of 0.09, 0.27, 0.09, and  $1.51 \text{ GJ}_{\text{ex}} \text{ ha}^{-1} \text{ yr}^{-1}$  for policy2016, policy20xx, policy20yy, and policy20zz, respectively. Although the average net result (taken over 30 years) is negative for policy20yy, the balance between avoided N fertilizer

and resource consumption becomes already positive in the short or medium term regarding the net results per year. The required time, called pay-back time ( $t_{\text{pb}}$ ), ranges from 9 (FMS7) to 26 years (FMS6) (Fig. 3). This indicates that policy20yy is a promising strategy in terms of exergy consumption.

The strategies involving compost will perform even better in reality as the amount of avoided N fertilizer is underestimated in the longer term. When compost is applied, the amount of N available for plants in the first year (effective N) is only 15%. The rest is divided among different N pools, which are more rapidly or slowly decomposable. However, the Demeter-tool does not account for increased mineralized N in the soil thanks to compost application in the previous years. As the effective N amounts 60 and 30% for slurry and FYM, respectively, the underestimation is also valid (but to a lower extent) for those fertilizers.

### 3.3. General comparison of agricultural policy strategies

The improvement potential of policy measures stimulating CC cultivation is specified by the difference between policy2016 and policy20xx. While some FMS obtained already good results in 2016, other FMS can still realize significant improvements (Fig. 2). The CAP's greening rules and MAP5 came into force in 2015, both stimulating CC cultivation but with MAP5 paying special attention to focus areas. Not all municipalities belonging to a certain FT-AR are within these focus areas. Nevertheless, an overall clear increase in the number of CCs can be noticed, suggesting a big impact of the CAP's greening rules on CC cultivation. As the implementation degree of the CAP strongly differs according to FMS, and the impact of compost also depends on the FMS, it can serve as an indication that a differentiated approach to stimulate certain policy strategies might be useful when striving for a more sustainable farming.



**Fig. 3.** Exergy benefit/loss per farm management system (FMS) ( $\text{GJ}_{\text{ex}} \text{ha}^{-1} \text{yr}^{-1}$ ) considering political strategies in the past (A) and in the future (B), compared to policy2014. Net results ( $\text{GJ}_{\text{ex}} \text{ha}^{-1} \text{yr}^{-1}$ ) and pay-back time ( $t_{\text{pb}}$ ) (for policy20yy) are given.

Parameter uncertainty has been calculated regarding the  $\text{SOC}_{\text{init}}$ . Error bars are only displayed with respect to the yield losses. Due to the model characteristics and the framework how to calculate CFs, the CFs of  $\text{SOC}^2$  are independent of the  $\text{SOC}_{\text{init}}$  (Boone et al., 2018a). Therefore, the results of Fig. 2A and C are independent of  $\text{SOC}_{\text{init}}$ . Taking into account the uncertainty of the yield surplus, policy20xx always displays the lowest yield surplus, while for some FMS (e.g. FMS4 and FMS5), there might be no clear favor for policy20yy or policy20zz. However, more research about uncertainty is needed. For instance, the indicators are aiming to estimate the impact in the long term. However, average climate data are used in the model, while several climate scenarios should be considered. Furthermore, only the uncertainty regarding  $\text{SOC}_{\text{init}}$  has been included, while a range of parameters could be discussed (e.g. soil density, carbon of manure). Due to data restrictions needed to enable uncertainty calculations, this is out of scope. Next, the uncertainty of the model to simulate SOC changes has been tested for Belgium (van Wesemael et al., 2005), while more research is needed regarding the EU-Rotate\_N model.

For a general overview across Flanders, maps are created to give an overview on the realized and potential impact of the CAP and other policies on SOC stock. They give a first rough indication of the improvement in terms of long-term productivity regarding SOC across Flanders thanks to policy measures. The calculation procedure and maps are presented in Appendix F.

To avoid burden shifting, it is important to combine the results of resource productivity and resource consumption. The results seems to be contradictory. For all FMS, policy\_noCC is positively evaluated in terms of resource footprint. Indeed, policy\_noCC has the lowest resource consumption, because this policy strategy entails no addition of extra manure nor CC cultivation. In contrast, policy\_noCC requires more mineral N fertilizers than policy2014. If the balance is made between resource consumption and avoided synthetic fertilizer consumption in terms of exergy, policy\_noCC is

the only policy strategy for which the exergy balance is positive for all FMS (i.e. exergy benefit) (Fig. 3). But, regarding Fig. 2, policy\_noCC does not contribute to long-term productivity. For the other strategies, the opposite is true. Only policy20yy gets a positive evaluation (in the short or medium term) for the two aspects. However, the results must be interpreted in a broader context. Although the average net results (in exergy) per year are often (slightly) negative (Fig. 3), the implementation of other policy strategies induces changes in the type of resources consumed, e.g. a reduction of mineral fertilizers mainly diminishes the consumption of fossil fuel and water resources, while CCs require mainly land resources (to produce CC seed). Furthermore, positive effects other than reduction in yield losses or need for N are not yet accounted for (see section 3.1). For instance, policy20zz combines the positive aspects of compost on soil quality while still utilizing manure (i.e., not contributing to manure surplus). For policy20yy, the long-term application of compost poses risks in terms of N and P leaching (D'Hose et al., 2016). This indicates the necessity to evaluate policy strategies not only for SOC or yield, but also in terms of resource consumption and the impact on the environment (e.g. eutrophication).

In addition to the impact of policy on the AoP natural resources, policy also highlights the importance of agriculture to tackle climate change. By stimulating certain policy strategies, the synthetic fertilizer consumption will change, which can easily be expressed in terms of savings of global warming potential (GWP). Furthermore, the research performed regarding SOC stock could be translated into possible carbon sequestration (and thus contributing to savings in GWP). In this way, the results could also be interpreted in terms of benefits related to climate change. However, this is out of scope of this study, as then, the whole life cycle should be taken into account: e.g. not only the benefit of compost (reduced need for N), but also the emissions during composting.



#### 4. Conclusions

In this study, we investigated to which extent policy affected or can affect the long-term resource productivity and resource footprint by comparing (potential) political measures that encourage certain LUPs. Subdividing the quite diverse Flemish agricultural sector into FMS allowed us to derive for each FMS the impact of policies in the past and in the future and to discover future opportunities in terms of compost use and cover crops.

This study shows that, although productivity is not their main goal, policies such as the CAP's greening measures and MAP5 significantly contribute to a better SOC and (to a lesser extent) productivity. Measures that stimulate the use of compost seem promising. However, it is important to consider also the resource footprint as only for one strategy, the resource consumption outweighs the benefit (i.e. reduction in N fertilizer) in the short or medium term, while also being beneficial in terms of resource productivity. It would, however, be interesting to elaborate this assessment of policy measures by not only including the provisioning function of agricultural soils, but also other ecosystem services (e.g. carbon sequestration, biodiversity), which may support a more refined weighting of alternative policy options.

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#### Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jclepro.2019.119000>.

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